NOT TO BE CITED WHTHOUT PRIOR REFERENCE TO THE AUTHORS

ICES CM 2008/R:18

A system for online assessment of fish welfare in aquaculture

Lars H. Stien[1], Trygve Gytre[1], Thomas Torgersen[1], Helge Sagen[2], Tore S. Kristiansen[1]

1. Research group: Animal Welfare, Institute of Marine Research, P.O. Box 1870 Nordnes, N-5817 Bergen, Norway.
2. The Norwegian Marine Data Centre, Institute of Marine Research, P.O. Box 1870 Nordnes, N-5817 Bergen, Norway.

Abstract

Aquaculture sea cages can now be more than 30 meters deep. It has therefore become next to impossible for fish farmers to form a complete picture of the welfare situation of the fish. It is consequently all-important to develop an automatic system for continuous assessment of fish welfare in sea cages. One such system under development is the Welfaremeter. The Welfaremeter consists of a profiling probe (CTD), a control unit, a database, an expert software program and an internet webpage. The probe measures temperature, oxygen, salinity, fluorescence and turbidity for each half meter downwards in the cage. The control unit determines how often the probe profiles the water column and sends the measurement data via the mobile phone network (GPRS) to a database at The Norwegian Marine Data Centre, Institute of Marine Research. These data are then analysed by the expert software which gives an evaluation of the environmental conditions in the cage as either very good, fair or potentially harmful for the fish. Future versions of the expert software will also give possible reasons for poor environmental conditions and advice for how the farmers, if possible, can remedy the situation or at least diminish harm to the fish. The high density of fish farms in many costal zones means that the Welfaremeter has potential as a future source of data for environmental and fisheries research. The purpose of this talk is to give an insight into the present prototype and how we plan to improve the system further.

Keywords: Fish welfare, CTD, GPRS, expert software

Contact author Lars H. Stien: Institute of Marine Research, P.O. Box 1870 Nordnes, N-5817 Bergen, Norway [tel: +47 472 91 029, e-mail: lars.stien@imr.no].

Introduction

The connection between good environmental conditions and healthy fish is clearly documented in aquaculture (Huntingford et al. 2006, Conte 2004, Black and Pickering 1998). In Norwegian Atlantic salmon (*Salmo salar* L.) aquaculture the sea cages can now be more than 45 meters in diameter and 30 meters deep. Although a single sea cage can contain salmon for more than one million US dollars the level of surveillance of the salmon and their environment is generally low. With little data about the actual living conditions of the fish it becomes difficult to study and gain knowledge about how the environment affects the salmon in the sea cage, and the fish farmer cannot document to buyers that the fish have lived under satisfactory conditions. The low surveillance level is both due to the lack of suitable surveillance equipment at an acceptable cost and the lack of computer systems to handle and interpret the large volume of data. It is therefore necessary to develop both suitable measurement systems and intelligent computer programs which can handle and interpret the data and then present it in an easy and understandable way to the fish farmer.

The Institute of Marine Research (Norway) has therefore in cooperation with Tendo Tech AS (Norway), SAIV AS(Norway) and Morten Hammersland programvare (Norway) developed a prototype of a measurement system that provides a profile of the environmental conditions from top to bottom of a sea cage at regular intervals, typical every two hours. The measurement system consists of a profiling CTD-probe and a control unit which elevates the probe up and down in the cage and after each profiling transmits the data via the mobile phone network (GPRS) to a central database at the Norwegian Marine Data Centre.

Intelligence can be defined as the ability to act purposefully based on comprehension. In line with this definition the Animal welfare research group at the Institute at Marine Research has started to design intelligent expert software for analysing and evaluating the welfare of fish in a sea cage based on the data received from the CTD-probe (see above). This software is based on modelling of salmon metabolism and the latest knowledge about how different environmental conditions affect salmon. The software will give two main indexes: A welfare index from 0 (terrible welfare) to 100 (excellent welfare) and an appetite index from 0 (no appetite) to 100 (very high appetite). The goal is that these indexes together will guide the farmer to good management and operation decisions in the daily running of the farm. It is for instance not advisable to perform a net change operation causing further stress to the fish if the fish are already suffering under poor environmental conditions. In case of poor conditions the system will therefore first warn the farmer, question the farmer about possible reasons for the poor welfare and then give the farmer advice on how to proceed.

At the time of writing, a prototype of the profiling measurement system and the expert software has been built and is undergoing trials at a commercial salmon farm in Austevoll, Norway. The prototype, the measurement system and the expert software together is called 'Welfaremeter' and live results from the ongoing trial can be seen at http://www.imr.no/welfaremeter. In the following we give a description of the measurement system, a short description of the modelling of salmon metabolism incorporated in the prototype, some measurement results from the trial and future plans for improvements of both the measurement system and the expert software.

The prototype

The Welfaremeter prototype consists of a profiling probe (CTD), a control unit, a database, an expert software program and an internet webpage. The probe measures temperature, oxygen, salinity, fluorescence and turbidity for each half meter downwards in the cage. The control unit determines how often the probe profiles the water column and sends the measurement data via the mobile phone network (GPRS) to a database at The Norwegian Marine Data Centre (NMD), Institute of Marine Research. These data are then analysed by the expert software which gives an evaluation of the environmental conditions in the cage and calculates a welfare index from 0 (terrible welfare) to 100 (excellent welfare). The results are then presented on the internet webpage.

The probe

The profiling probe is a standard CTD (SAIV MINI STD/CTD – model SD204, SAIV AS, Norway) and measures conductivity, temperature and depth and calculates the relative amount of salts in the seawater (salinity) based on the conductivity and temperature measurements. In addition to this, sensors for measuring dissolved oxygen (OxyGuard Alpha Probe, Oxyguard, Denmark), turbidity (Seapoint Turbidity Meter, Seapoint, Sensors inc., USA) and fluorescence (Seapoint Chlorophyll Fluorometer, Seapoint Sensors inc., USA) are also attached to the probe. The probe is pulled up and down in the sea cage by a winch on the control unit and sends data to the control unit via radio every time it re-emerges from a profiling. In order to reduce bio fouling problems the probe is positioned slightly above sea level between the measurement cycles. This causes any small aquatic organisms on the probe surfaces to dry out and die. It also makes it possible to calibrate the oxygen probe in air every day for consistent measurements.

The control unit

The control unit consists of a winch(Orbit Multivinsj, Orbit AquaCam, Norway) and a mobile phone terminal (Siemens TC65 GSM Modem, Siemens AG, Germany), and has two main tasks: (1) to raise and lower the probe and (2) to send the measurements of the probe onwards to the central database. The data is sent as a GPRS message (GPRS = General Packet Radio Service) via the GSM mobile network. The system is therefore not dependent on an internet connection on the farm, only mobile phone coverage.

The database

To ensure safe storage of the data the database is located at NMD which has a solid IT infrastructure with a firewall, uninterruptible power supply (UPS), backup systems, SMS alerts to the operations people and have historically had high up-time. The database is implemented in the open source relational database system PostgreSQL (http://www.postgresql.org) and runs on an Apache Tomcat server (The Apache Software Foundation, http://www.apache.org). A simplified conceptual schema (Halpin 1999) of the database design is shown in Figure 1.

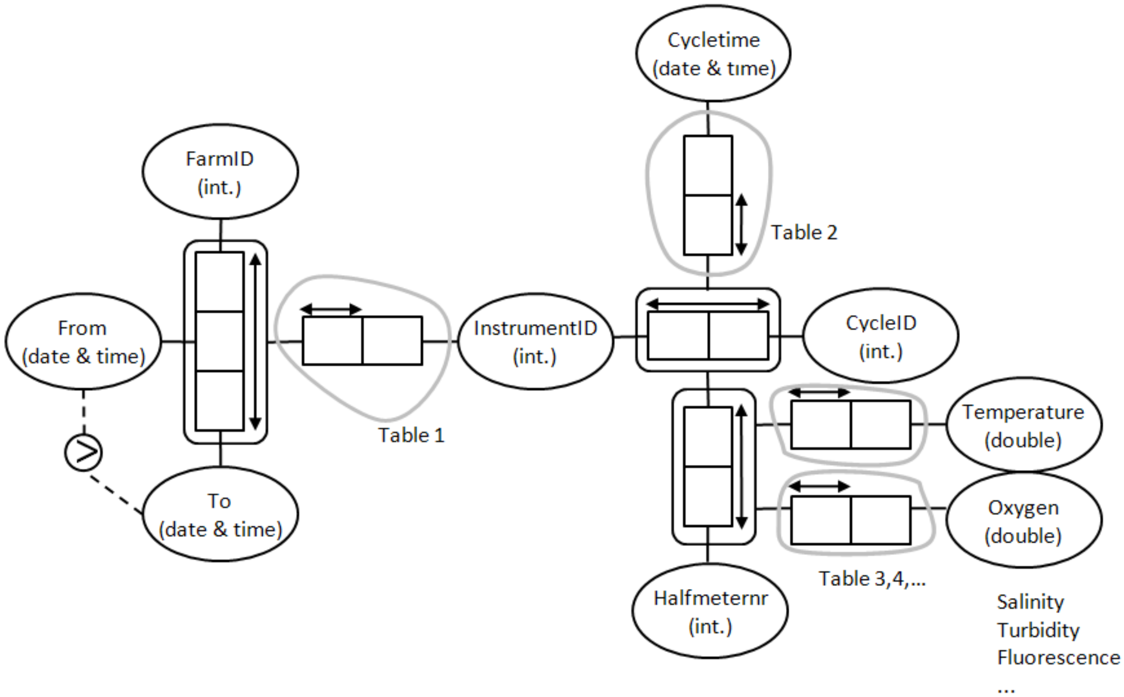

Figure 1: Simplified conceptual schema of the database used by the Welfaremeter-prototype.

The expert software

The expert software of the prototype is based on knowledge about how Atlantic salmon react to different environmental conditions and mathematical modelling of salmon metabolism given the measured environmental conditions (metabolism is the sum of all chemical reactions in an organism that lead to continued life, growth and reproduction). For instance the chemical processes in the cells decelerate at low water temperatures, while too high temperatures may lead to collapse of the metabolism(Pennell and Barton 1996). Satisfactory temperatures for salmon lies in the range between about 7 and about 17 ° C. Further, low oxygen saturation will lead to higher metabolic costs of oxygen uptake and lower maximum uptake rates. Changes in environmental conditions may lead to stress-induced increase in oxygen consumption and oxygen consuming physiological acclimation processes. Over time these responses will habituate and diminish.

When new data arrive in the database, it is immediately analysed by the expert software and classified as good, fair or potentially harmful to fish. The expert software also calculates a welfare index from 0 (terrible welfare) to 100 (excellent welfare). This index is based on modelling of metabolic scope (the salmon’s capacity to extract oxygen beyond its basic needs from the water under the current environmental conditions) and factorial scope (the maximum continuous oxygen uptake divided by the standard oxygen consumption, reflecting the salmon’s robustness for stress and environmental perturbations under the current environmental conditions). The modelling behind these two parameters has been developed in the software package Stella (Isee systems, USA) and is based on the ecophysiological growth model Ecophys.fish(Neill et al. 2004). The full salmon model will be published elsewhere. A screenshot of the Stella model for salmon metabolism is shown in Figure 2. A trial version of this model is included in the prototype expert software, calculating metabolic scope and factorial scope.

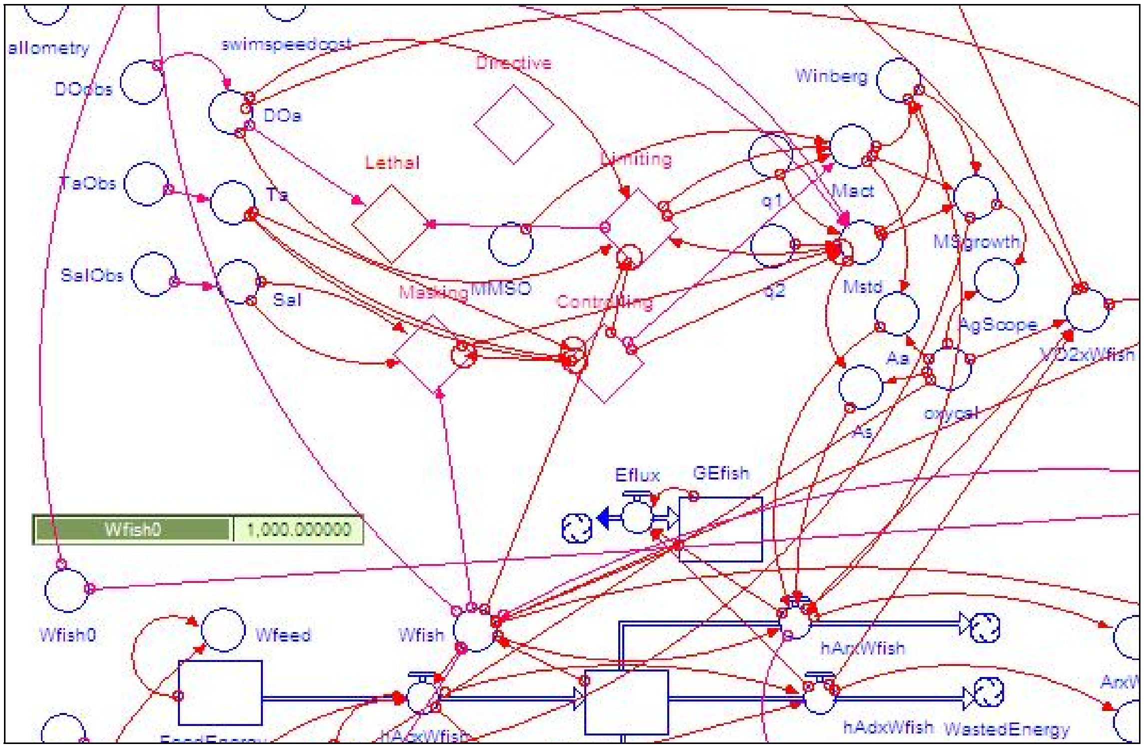

Figure 2: Screenshot of part of the modelling of salmon metabolism in the software package Stella.

The new measurements and the results from the modelling by the expert software are made available on the internet webpage as soon as the calculations are finished (2-3 seconds).

The internet webpage

The first version of the internet webpage is available at http://www.imr.no/welfaremeter and displays live data from the ongoing trial. The main visible features of the webpage are three graphs and a speedometer (Figure 3). The speedometer gives the welfare index. The top graph on the page illustrates the environmental conditions in the cage from top to bottom. The measurements by the probe are indicated by points, the x-axis gives the scale of the selected environmental parameter and the y-axis gives the depth. The background of the graph is divided into red, yellow and green zones. If a measurement is in a red zone, it means that the conditions at this depth are potentially harmful to the fish. Yellow zone indicates less good conditions and green zone indicates good conditions. The user can easily choose between the different environmental parameters (including metabolic scope and factorial scope) by clicking on a menu at the side of the graph. The other two graphs are based on similar principles, but specify the development over time.

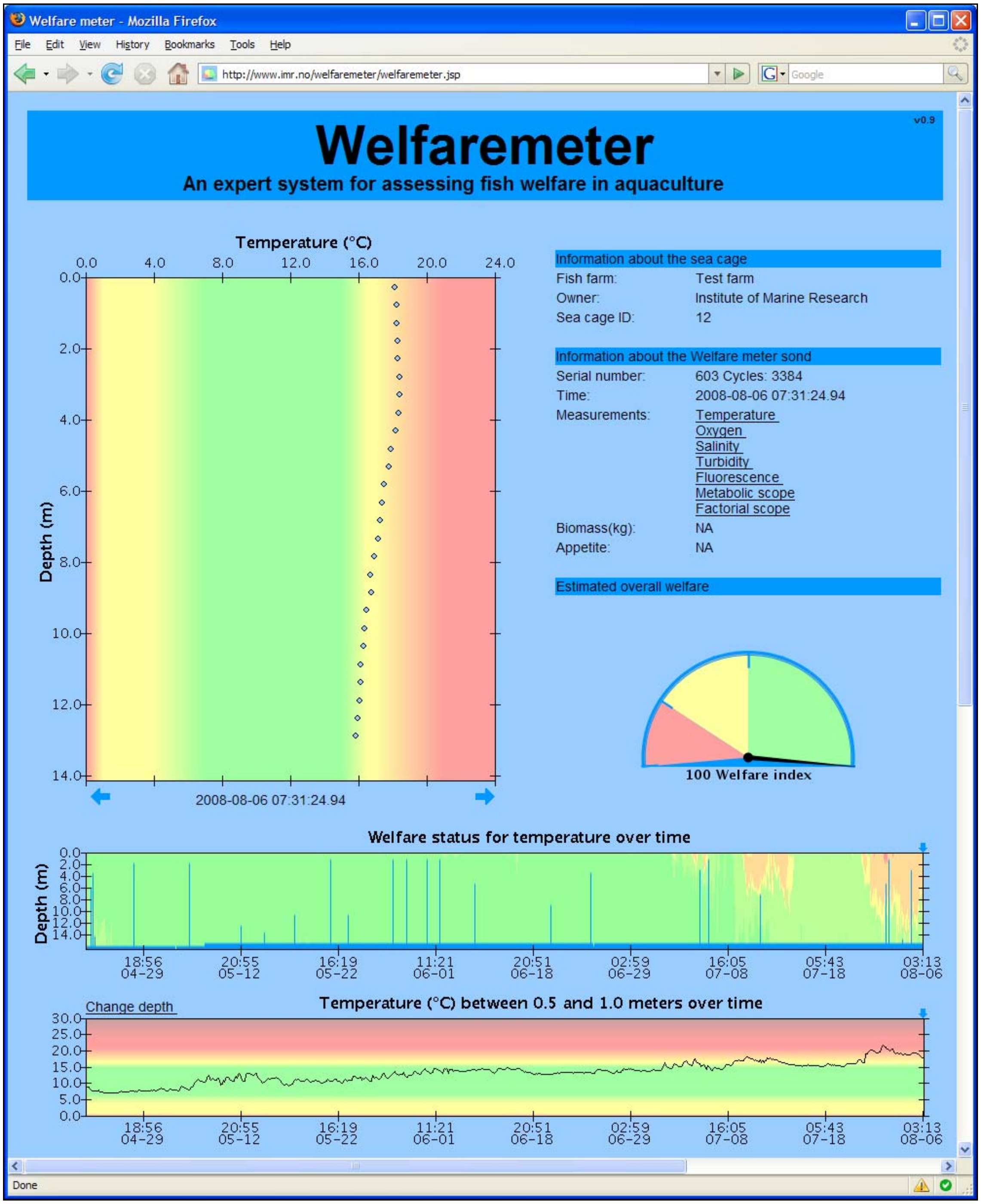

Figure 3: The Welfaremeter internet page (http://www.imr.no/welfaremeter). The user has selected to view temperature. The main graph shows the current temperature from top to bottom of the sea cage and the two other graphs show welfare and temperature over time.

Some data from the test period

The prototype has now been successfully tested at the fish farm for nearly one year. During this time we have made many interesting observations. One example of this is that the fish at the first feeding each day often consume oxygen at such a rate that the flux of new water through the net is not sufficient to maintain the oxygen level of the water inside the cage (Figure 4).

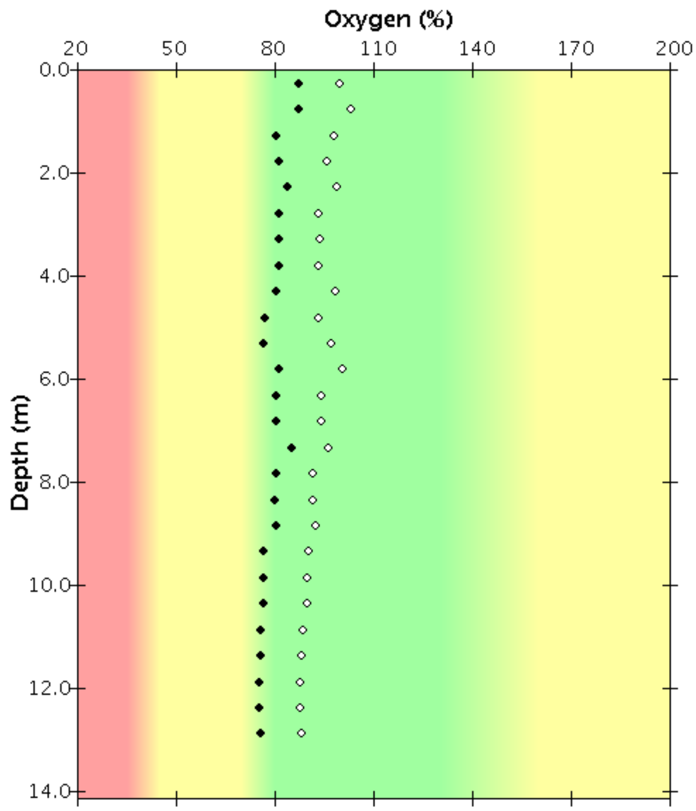

Figure 4: The oxygen content of the water throughout the water column of the sea cage for two separate measurement cycles. The white dots are from the cycle before the first feeding of the day and the black dots are from the cycle after the first feeding of the day. These cycles are from 2008-07-31; this was a warm summer day.

The sea temperature at 3 to 3.5 meters depth increased steadily from about 8 °C in April to nearly 20 °C in late July and early August (Figure 5). If this temperature is maintained over long periods of time it may harm the fish and reduce its growth performance. Luckily the water is colder further down in the cage as shown in the screenshot in Figure 3. Both the oxygen and the salinity content decrease slightly throughout the period, but both stayed within the green comfort zone (Figure 5). The decrease in salinity is explained by melting snow in the Norwegian mountains creating a layer of brackish water in the top of the water column. The decrease in oxygen content may be explained by that the fish consume more oxygen as the temperature rises. It is also apparent that the oxygen content of the water fluctuates throughout the individual days. As discussed above, this can be explained by temporary changes in the oxygen consumption of the fish (Figure 4).

The factorial scope calculated by the prototype expert software decreases from June and onwards. This is primarily explained by the increase in temperature, but also the slight decrease in oxygen. We are however, unsure on where to put the red, yellow and green zones for the factorial scope(it should be noted that the factorial scope relates to the standard and not the routine metabolism.) It is possible that the yellow zone should be extended to 2.0. This is the focus of present research.

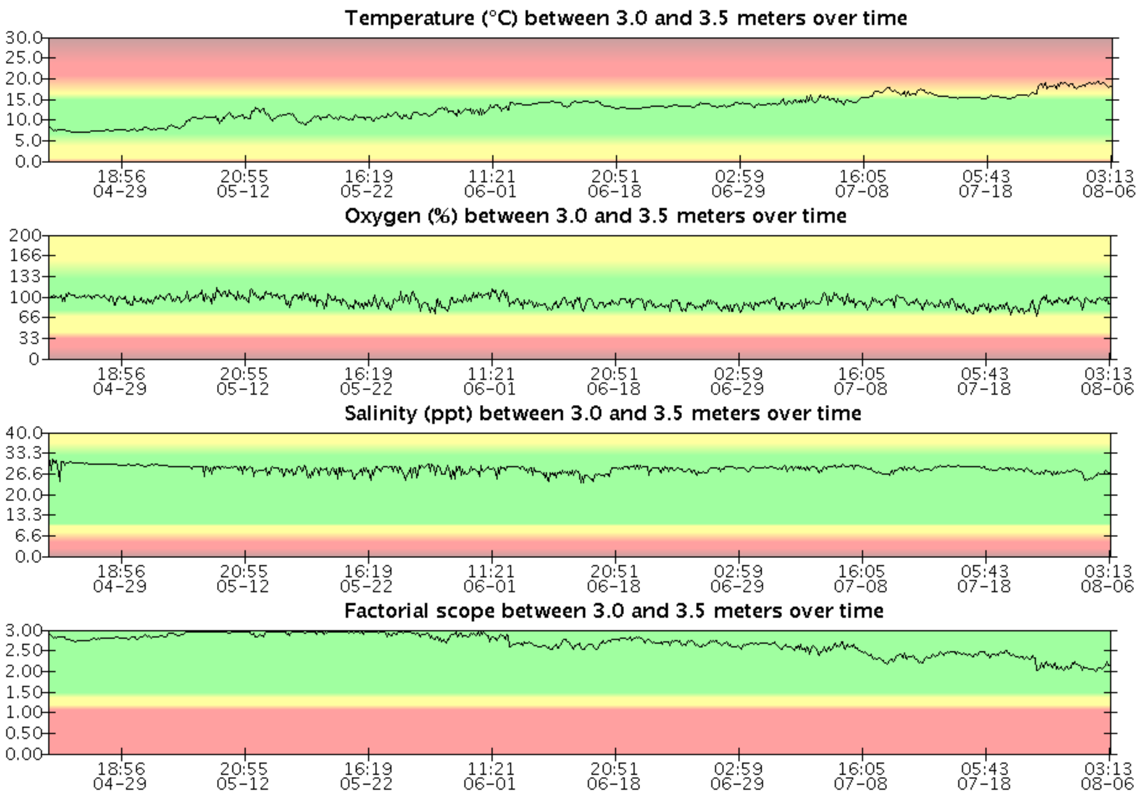

Figure 5: Changes in temperature, oxygen, salinity and factorial scope from April to August. Green zones indicate that the parameter is well within the comfort zone of Atlantic salmon, red zone indicate that long term exposure to such environmental conditions will harm the fish and yellow zone is the border area between the red and green zones.

Future plans

We want to develop a version of the Welfaremeter-measuring-system where the control unit, winch and probe are all gathered on a dedicated raft or float. By having all components in one float the system becomes easy to install in any sea cage. Although the boundaries of the cage moderate waves coming into the cage it is necessary to design a float able to withstand though conditions in open water. The float will therefore have a low centre of gravity and as little possible surface for the wind to catch a hold off as possible. We also plan to install a web server in the float. New data will be placed on the server and accessible from the internet by its URL and the correct password. In this way both single users and institutional multiusers may collect their own secured data. The goal is to make the measurement system independent of the expert system. A user may choose to only buy the measurements system, and if he or she is a fish farmer in addition also buy access to the expert system to get a qualified assessment of fish welfare. Similarly we want to make it possible for instruments by third party producers to communicate with the Welfaremeter expert software in order to make the expert software independent of a specific measuring system.

In order to calculate dissolved oxygen in incoming water and water flow to the cage we will develop a reference probe which measures oxygen and current outside the cage. This probe will be built based on the on the same technology as for the Welfaremeter prototype, but the profiling probe will be replaced by three stationary probes which only have sensors for oxygen, temperature and current. These three probes will be attached along a cable from the float to bottom. An especially designed cable for this purpose has already been ordered from Anderaa Instruments AS, Norway. Using this cable the system will easily be able to be expanded by adding further probes if needed.

We also want to upgrade the internet user interface for two-way communication, allowing the fish farmer to type in or upload information about feeding, husbandry routines, diseases, mortality, and possible stressful conditions. In the EU-project FASTFISH we developed an internet application for manual registration of farm data called FastTool (http://www.imr.no/fasttool). This included data about feeding, farming practices, fish behaviour and fish appearance. We therefore plan to take the best from FastTool and include it into the Welfaremeter internet webpage. In this way the expert system will not only get information about the environment but also about important factors for fish welfare as stocking density, feeding regime and diseases. The affect of a given set of environmental parameter values on fish physiology and behaviour is not static, and not only the amplitudes, but also the temporal scales of environmental changes have substantial effect on fish welfare and performance, i.e. ability to cope with the environment. We are therefore going to include more sophisticated models of salmon metabolism into the expert system, including data-based rates of acclimation and habituation. We also plan to create models that based on the calculated metabolism parameters and input from the farmer about husbandry, fish behaviour, diseases etc. give an assessment of the situation at the farm and advice to the fish farmer on how to improve fish welfare.

The goal is to develop the Welfarmeter into a standard product in aquaculture. Considering that there are more than 1000 fish farms along the Norwegian coast alone, the Welfaremeter has a huge potential as a future source of frequent and detailed environmental data about the sea water along the Norwegian coast, especially since the equipment will be placed on fish farms which will have an own interest in maintaining and keeping the measurement equipments running.

Acknowledgements

This project has been carried out with financial support from three different sources: (1) Bergen Teknologioverføring AS (BTO).BTO supports research institutions in Bergen in commercialisation and technology transfer of research results. (2) The Commission of the European Communities, specific RTD programme “Specific Support to Policies”, SSP-2004-4-FISH – Area 8.1.B.1.3: Task 8, Project 022720 FASTFISH - On farm assessment of stress levels in fish (2006–2009). It does not necessarily reflect its views and in no way anticipates the Commission’s future policy in this area. (3)The Research Council of Norway, Project 173538 PHYSBEWEL- Physiological and behavioural indicators for fish welfare assessment in aquaculture and fish capture.

References

Black, K. D. & A. D. Pickering. 1998. *Biology of farmed fish*. Sheffield: Sheffield Academic Press.

Conte, F. (2004) Stress and the welfare of cultured fish. *Applied Animal Behaviour Science,* 86**,** 205-223.

Halpin, T. A. 1999. *Conceptual schema & relational database design*. Bellevue WA: WytLytPub.

Huntingford, F. A., C. Adams, V. A. Braithwaite, S. Kadri, T. G. Pottinger, P. Sandoe & J. F. Turnbull (2006) Current issues in fish welfare. *Journal of Fish Biology,* 68**,** 332-372.

Neill, W. H., T. S. Brandes, B. J. Burke, S. R. Craig, L. V. Dimichele, K. Duchon, R. E. Edwards, L. P. Fontaine, D. M. Gatlin, C. Hutchins, J. M. Miller, B. J. Ponwith, C. J. Stahl, J. R. Tomasso & R. R. Vega (2004) Ecophys.Fish: A simulation model of fish growth in time-varying environmental regimes. *Reviews in Fisheries Science,* 12**,** 233-288.

Pennell, W. & B. A. Barton. 1996. *Principles of Salmonid Culture*. Amsterdam: Elsevier Science.